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Abstract

CARBIDE FUEL FABRICATION AND PERFORMANCE

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Development of massive uranium monocarbide as a nuclear fuel has included tests of several preparative methods; investigation of the binary composition range from "hypo" (less than the stoichiometric 4.8 wt % C), to greater carbon contents ("hyper"); and exploration of the effects of additives and the properties of ternary systems. Various fuel-element designs have been tested both in and out of pile. These were made with and without a liquid-metal thermal bond, in a variety of cladding compositions - e.g., type 304 stainless steel, Nb/1% Zr, and tungsten. The greatest application thus far has been in sodium cooled reactors. Model elements have reached 5000 MWd/tonne burnup in the Sodium Reactor Experiment (SRE). Ten full-scale UC elements have been operating since September 1963 in the first core loading of the 81-MW(e) Hallam Nuclear Power Facility (HNPF).

All the above fuel elements are clusters of long rods, each made up of UC slugs, thermally bonded by sodium to thin-wall cladding of type 304 stainless steel. The fuel is arc-melted and cast hypo-UC (4.4 - 4.8). A typical heat of enriched material starts with a total charge of 50 to 65 kg and results in a pour of 20 to 25 kg, which can produce about 50 slugs, 0.5 in diameter (1.27 cm) x 6 in. long (15 cm). As of January, 1964 more than 12 000 kg of slugs had been prepared in this manner, including 2000 kg of enriched material. Over-all process yields indicate that with enrichment near 3 wt % U-235, fabrication cost of complete fuel elements would not exceed $100/kg of contained U.

Irradiation behavior of fuel elements made with hypo-UC, sodium bonded to stainless steel cladding, is projected to burnup of 25 000 MWd/tonne at limitations now estimated as follows:

Carbon range:	4.5 to 4.8 wt %
Maximum fuel center temperature:	1800F (980C)
Maximum cladding temperature:	1250F (675C)

These conditions permit linear heat rates up to 26 kW/ft (865w/cm), and specific power of 50 kW/kg U in practical fuel element designs. Allowance may be made readily to accommodate anticipated dimensional chances and fission-gas release. Higher temperature performance appears possible with a narrower range of carbon content about stoichiometric and with a more refractory metal cladding.

In preparing carbide fuel, powder-metallurgy techniques are feasible if the dimensions are too small for casting, if a controlled density is required, or if solid solution alloys are of interest. Bodies with more than 95% of theoretical density have been reproducibly made by hot isostatic pressing of crushed arc-cast UC in niobium containers (10 000 lb/in.^{2} -- (7 kg/mm^2) -- for sh at temperatures between 1500 and 1600C). A comparable product is obtained by cold pressing of powders and binder at 50 ton/in.^{2} (70 kg/mm^2), followed by sintering at 1800C. Also, spherical carbide alloy particles have been prepared in a high intensity arc. Irradiation tests have been made to evaluate composition and fabrication process effects.

Thermochemical data and the results of experimental determinations are available to establish maximum operating temperatures at which UC and a number of potential cladding materials are compatible.

Studies of ternary systems have resulted in proposed isothermal sections of the following phase diagrams: U-C-W; U-C-Mo; U-C-Re ; and U-C-Nb. A complete range of solid solutions has been found to exist between UC and UN; and the existence has been indicated of solid solutions of U(C,N,O).